Migration Rate and Behaviour of Adult Sockeye and Chum Salmon Through Trained and Untrained Sections of the Lower Fraser River

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MIGRATION RATE AND BEHAVIOUR OF ADULT SOCKEYE AND CHUM SALMON THROUGH TRAINED AND UNTRAINED SECTIONS OF THE LOWER FRASER RIVER

by

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ABSTRACT

Rosberg, G.E. and G.L. Greer. 1985. Migration rate and behaviour of adult sockeye and chum salmon through trained and untrained sections of the lower Fraser River. Can. Tech. Rep. Fish. Aquat. Sci. 1349: 25 p.

Migrating adult sockeye (Oncorhynchus nerka) and chum (O. keta) salmon were captured in the lower reaches of the Fraser River and fitted internally with radio-telemetry tags. The migration speeds of the released fish were determined over tracks ranging from approximately 3-19 km in the area between Sandheads and New Westminster. Mean absolute ground speed for sockeye and chum was similar (0.55±0.18 m/sec and 0.46±0.18 m/sec, resp.) but mean speed relative to body length (L) was greater for sockeye because of their smaller size (0.98±0.32 L/sec vs 0.58±0.22 L/sec for chum). For both species, migration speed was greater through the trained sections of the river than the untrained sections (sockeye: 1.03±0.12 m/sec vs 0.62±0.12 m/sec; chum: 0.69±0.06 m/sec vs 0.49±0.02 m/sec). Radio-tagged salmon released in the slack water behind training walls returned via the downstream end to the main channel, and resumed upstream migration, in times ranging from immediate to 10.5 h. Hydroacoustic monitoring of river transects indicated no significant effect of tide or vertical and horizontal distribution of salmon-sized targets in a lower, untrained reach of the river. Larger numbers of targets were recorded in a trained section on ebb tides with some indication of a significant horizontal distribution and interaction between these two factors. Hydroacoustic monitoring of a fish passage opening at the upstream end of a training wall showed that salmon also return to the main channel via this route and do so in larger numbers on ebb tide when river flows are higher. Results of the present study suggest that existing training structures in the lower Fraser mainstem do not seriously impede migratory progress of adult sockeye and chum salmon.

Key Words: radio telemetry, hydroacoustic monitoring, adult sockeye salmon, adult chum salmon, migration, behaviour, training walls.

RÉSUMÉ

Rosberg, G. E. and G. L. Greer. 1985. Migration rate and behaviour of adult sockeye and chum salmon through trained and untrained sections of the lower Fraser River. Can. Tech. Rep. Fish. Aquat. Sci. 1349: 25 p.

Des saumons rouges (Oncorhynchus nerka) et kétas (O. keta) migrateurs adultes on été capturés dans les parties d'aval du fleuve et munis d'émetteurs radio internes. Les vitesses de migration des poissons relâchés one été déterminées à partir de distances parcourues variant de 3 à 19 km environ dans la région entre Sandheads et New Westminster. La vitesse moyenne absolue par rapport au sol était semblable chez le rouge et le kéta (0.55 ± 0.18 m/sec et 0.46 ± 0.18 m/sec respectivement), mais la vitesse moyenne par rapport à la longueur du corps (L) était plus élevée chez le saumon rouge à cause de sa taille inférieure (0.98 ± 0.32 L/sec v. 0.58 ± 0.22 L/sec chez le kéta). Chez les deux espèces, la vitesse de migration était plus élevée dans les sections aménagées du fleuve que dans les sections sauvages (saumon rouge: 1.03 ± 0.12 m/sec v. 0.62 ± 0.12 m/sec; saumon kéta: 0.69 ± 0.06 m/sec v. 0.49 ± 0.02 m/sec). Les saumons munis d'émetteurs radio relâchés dans les eaux dormantes en arrière d'ouvrages de régularisation sont retournés par l'extrémité d'aval vers le chenal principal pour reprendre la montaison; la durée de cette manoeuvre a varié de l'immédiat à 10.5 h. La surveillance hydroacoustique de transects fluviaux n'a pas révélé d'incidence importante de la marée ou de la distribution verticale et horizontale de cibles de la taille du saumon dans une section d'aval non aménagée. Un plus grand nombre de cibles ont été enregistrées à marée basse dans une section aménagée en plus de certains signes d'une importante distribution horizontale et d'une interaction entre ces deux facteurs. La surveillance hydroacoustique de l'entrée d'une passe migratoire située à l'extrémité d'amont d'un ouvrage de régularisation a révélé que le saumon retourne aussi au chenal principal par cette route et qu'un grande nombre le fait à marée basse quand le débit fluvial est plus élevé. Les résultats de la présente étude portent à croire que les ouvrages de régularisation du cours principal inférieur du Fraser n'entravent pas sérieusement la montaison des saumons rouges et kétas adultes.

Mots-clés: émetteurs radio, surveillance hydroacoustique, saumon rouge adulte, saumon kéta adulte, migration, comportement, ouvrages de régularisation

INTRODUCTION

The Fraser River ranks among the world's most important salmon rivers. In North America, the Fraser and its tributaries contribute the greatest numbers of salmon to the Pacific Coast salmon fisheries. The lower Fraser is a major migratory corridor for the five species of adult Pacific salmon returning to interior British Columbia streams and for their young descending from natal streams and lakes to oceanic rearing areas. The numbers of adult salmonids transiting the lower Fraser can total a thousand per day from mid-June through late December. During arrival of distinct sockeye (Oncorhynchus nerka) races such as the Adams River run, however, the migration can reach one hundred thousand fish daily.

The lower reaches of the Fraser River mainstem between Sandheads and New Westminster (ca. 35 km) are within tidal influence and subjected to continual deposition of sediments. Training walls, consisting of groins of rip-rap or closely apposed vertical pilings constructed over sections of this part of the river, are set varying distances from the river shoreline and feature openings in the upstream end for fish passage. These training structures promote hydraulic scouring of the river bed and seaward transport of sediments by the higher water velocities thereby assisting maintenance of a navigable channel for deep-draft vessels.

Rate of flow is the environmental stimulus most commonly cited as controlling salmonid upstream migration although it can be modified by other factors including temperature, water quality, weather, light intensity, wind and tidal action (Banks, 1969). Gilhousen (1960) suggested that Fraser River discharge and related oceanographic characteristics of the resulting plume in the Strait of Georgia affect the entry of adult salmon into the lower river. During years with low runoff, for example, the Adams River sockeye run has been known to delay off the mouth of the Fraser. Immediate river entry is characteristic of sockeye races but peak arrival normally is in July or early August when river discharge is still moderately high. Delays related to low discharge become more pronounced for late arriving sockeye races. Subsequent to river entry, however, total discharge may not be the only environmental factor that controls rate of migration. Tagaki and Smith (1973), for example, concluded that Skeena and Babine River sockeye select specific velocities and ascend the river predictably regardless of discharge.

Prior to entering freshwater, anadromous salmonids undergo physiological changes concurrent with onset of their reproductive phase. One significant change occurring near the river mouth is reduction or ceasation of feeding. Subsequently, the salmon rely on stored energy reserves to complete upstream migration and reproduction. Migratory delays could tax essential energy reserves and possibly have a direct effect on reproductive success. Those races that spawn in downstream Fraser River areas would be more tolerant of migratory delays and not as restricted by fine-tuned energy and time budgets (Andrew and Geen, 1960). Of the five species of Pacific salmon, sockeye appear to be the least tolerant of migratory interference and headwater spawning sockeye populations are likely to be on the strictest energy budgets. For example, Stuart sockeye races use 90% of their body fat reserves from the time of Fraser River entry to the completion of the spawning act (Idler and Clemens, 1959).

Thus a delay of only a few days could compromise reproductive success for early Stuart sockeye since they have long distances to travel to their headwater spawning grounds (Andrew and Geen, 1960).

Proposed improvements to the lower Fraser shipping channel through further entrainment has raised concern that altered flow characteristics of the river may cause migration delays if adults stray from the main channel and hold or become disoriented in the calmer waters behind the training structures, or otherwise change their migration behaviour through this section of the river. The present study describes migratory behaviour and pathways of adult sockeye and chum (O. keta) salmon ascending the lower river and their behavioural responses to existing training structures.

MATERIALS AND METHODS

The study involved the use of two field techniques: hydroacoustic monitoring and location telemetry of radio-tagged fish. The hydroacoustic surveys provided descriptions of pathways of migrating adult salmon in trained and untrained sections of the river and fish utilization of openings at the head of training structures. Radio telemetry was used to obtain descriptive data on the locomotory behaviour of individual fish and their reactions to several training structures. The field work was carried out during the fall of 1978 from 20 September through 30 November.

Hydroacoustic surveys

The data acquisition system used for the hydroacoustic surveys consisted of a Simrad EY-M echosounder equipped with a wide-angle transducer (27° full angle), a Nakamichi 550 cassette tape recorder, and a Hewlett-Packard 1703A oscilloscope. The instruments were independently powered with 12 volt batteries to isolate the tape recorder from the echo sounder.

Hydroacoustic surveys consisted of two components: transecting at set stations and stationary monitoring at the upstream opening of a training structure. The transects consisted of four acoustical cross-sections taken across the river from the south to the north bank and perpendicular to river flow. Replicates were completed 1-2 times per day at each of four stations. Stations 1-3 were located near New Westminster at the upper end of Annacis Island and were selected because of their proximity to several training structures (Fig. 1). Station 4, located downstream at Tilbury Island, provided a comparison of the migratory behaviour of salmon in an untrained section of river. During transect samplings, the transducer was mounted in a hydrodynamically designed towing body suspended from a horizontal beam fixed to the survey vessel.

To determine the distribution of fish at each transect, river cross-sections were divided into three equal segments horizontally and three depths vertically (0-5 m, 5-10 m, and 10-15 m) to yield nine sectors for each transect (Fig. 1). Target counts in each of the sectors were made from tape records. A counting threshold of -35 dB was selected to screen out fish targets smaller than

adult salmon.

Monitoring of fish passage from behind a training structure was done by floating a stationary transducer in the opening at the upstream end of the rip-rap structure at the Fraser Surrey Container Dock near transect Station 1 (Fig. 1). This location was monitored continuously from 2000 hours on September 20 through 1400 hours on September 22. Target counts and water depths below the transducer were displayed on an echo counting device and recorded hourly.

Radio telemetry

Radio telemetry was employed to investigate the migration of individual salmon as they passed through the lower portions of the Fraser River in transit to upstream spawning grounds. The studies were designed to identify patterns of migratory behaviour that could be attributed to the influence of existing training structures. Tagging and releases were conducted from 23 September through 27 November 1978.

The telemetry equipment (Smith Root) consisted of internal-type radio transmitters and mobile and staionary receivers. Transmitter specifications were: frequency, 40.6 to 40.7 MHz; power, 90 milliwatts at 50 MHz; pulse rate, 0.5 to 4.0 per second; range, 600 to 1200 metres; length, 9 cm; diameter, 2 cm.

Receiving equipment was mounted on tracking vessels and employed loop antennas for directional reception and omnidirectional whip antennas for range reception. Fish and tracking vessel locations were plotted by azimuths taken with a compass. A stationary automatic recording device capable of scanning 10 frequencies simultaneously was established upstream on the Pattullo railway bridge (Fig. 1) to record the arrival of subject fish at this location and to enable calculation of total migration time through the study area.

Fish capture and releases

Sockeye salmon were captured with a shallow draft gillnet (4.5 x 67.7 m; 15.2 cm stretch mesh) set from a skiff. Fish were quickly cut out of the net on capture and placed in live holding containers (1 m x 2 m x 0.5 m). Chum salmon were obtained from a Federal Fisheries test fishery gillnetter. Only those fish uninjured by gillnet capture and large enough for tagging were used: all others were released immediately. The size range (fork length) of the sockeye used was 590 - 610 mm and the range for chum was 710 - 850 mm.

Insertion of the radio tag into the stomach of captured fish was facilitated with a wooden dowel. The antenna from the radio transmitter was anchored to the vomer with a fish hook. Prior to release, tagged fish were held submerged (ca. 2 m) a minimum of 24 hours at predesignated release sites in pens constructed from perforated plastic pipes (1 m by 30 cm diameter) and equipped with removable caps.

Releases of radio-tagged fish were concentrated in the mainstem from Tilbury Island to Purfleet Point on the downstream end of Annacis Island (Fig. 1). Releases also were conducted behind training structures on both sides of the river downstream of Shoal Point on Annacis Island. Only those fish demonstrating consistent upstream movement were included in calculations of

ground speed since erratic upstream or downstream movement following release could be indicative of injury or handling stress. In addition, to reduce the possibility of incorporating into the estimates initial escape responses following release, the transit time and distance to the first "sighting" for each radio track were not used in the computations.

RESULTS

Migration speeds of adult salmon in the lower Fraser River

Typical movements of radio-tagged salmon released in the Fraser River mainstem are depicted in Figs. 2-4. Migration speeds for radio-tagged chum and sockeye released in the mainstem and tracked as they moved upstream through the study area are shown in Table 1. Radio-tagged sockeye salmon moved upstream at a mean rate of 0.55 ± 0.18 m/sec while chum moved at a mean rate of 0.46 ± 0.18 m/sec. The absolute ground speed for the two species were not significantly different; expressed in relative ground speed L/sec (body lengths/sec), however, sockeye migrated through the study area significantly faster ($p < 0.05$) than chum.

A comparison of the speeds of individual radio-tagged fish that moved consistently upstream and tracked continously over flood and ebb tides is shown in Table 2. There was no significant difference in migration speeds over the different phases of the tidal cycle for either chum or sockeye.

Table 3 shows a comparison of the migration speeds for sockeye and chum as they moved through trained and untrained reaches of the lower river. Both species of tagged fish moved significantly faster ($p < 0.05$) through the trained section for speeds expressed in m/sec and L/sec.

Horizontal and vertical distribution of adults and the effect of tide

Patterns in the horizontal and vertical distributions of migrant fish were determined from hydroacoustic data from transecting Stations 1, 3 and 4 (Fig. 1), collected during distinct ebb and flood portions of the tidal cycle. The hydroacoustic data was converted to a relative number of targets detected in each of the river sectors and arc sine transformed. Probability values for five combinations of three factors examined by ANOVA are presented in Table 4.The results indicate that the distribution and frequency of detected targets varied from station to station, with horizontal and vertical distribution patterns more apparent at the upstream stations in a trained reach of the river. In addition, the effect of tide on the relative abundance of targets appeared to become more pronounced upstream. At station 4 located downstream near Tilbury Island in an untrained section of river, there was no significant difference in the relative number of targets recorded over flood and ebb tides. In addition, the targets at this station showed random vertical and horizontal distribution at all times. At upstream stations, however, migrants appeared to exhibit a preference for certain locations in the channel cross-section. At Station 3 near Gundersen Slough (Fig. 1), the significant difference ($p < 0.05$; Table 4) in horizontal distribution was due to a larger relative number of targets recorded on the south

side of the river. There was also a significant interaction ($p < 0.05$) between tide and this horizontal distribution; on ebb tides, there was substantial increase in the numbers of south side migrants. As found at Station 4 farther downstream, there were no changes evident in vertical distribution at the upstream stations that could be attributed to flood or ebb tides, however. Although greater numbers of targets were recorded at Station 3 during ebb, tidal influence per se was not significant. At Station 1 near Shoal Point at the upstream end of a trained reach, tide appeared to be a dominant influence and significantly greater ($p < 0.05$) numbers of fish were recorded during ebb in all nine sectors of the transect cross-section. Horizonatal distribution appeared to be random but vertical distribution ($p < 0.01$) was primarily in the surface and mid-water depths. There was no interaction between tide and horizontal or vertical distribution at Station 1.

For comparison with these results, similar analyses were performed on IPSFC Cottonwood (near the present Station 4 location) hydroacoustic data collected 30 July to 5 August 1977, a period when large numbers of sockeye migrants were moving through the lower river. Again, no difference in the vertical distribution of targets was apparent over flood and ebb tides. However, the IPSFC acoustic data did show greater numbers of targets ($p < 0.10$) horizontally distributed on the south side of the channel at ebb tide but this distribution became random during flood tide.

Acoustic data collected by the IPSFC at Mission in September 1977 also was examined for comparison of the spatial distribution of migrants at a location in the river far upstream where tide has little influence on river flow. From a total of 979 target counts in the 3 x 3 array of river sectors perpendicular to the channel (see table below), it was apparent the salmon preferred the sides and bottom of the channel at this upriver location and used the surface mid-channel sectors less extensively. The river velocity profile constructed from data obtained by the Water Survey of Canada (M. Concalves, per. comm.) for 7 September 1977 at Mission confirms that the fish would be avoiding the higher velocities in the mid-channel surface waters by migrating in edge zones near the sides and bottom of the river. Moreover, from the cross-channel profile, peak velocity is skewed toward the north bank of the river, and is opposite to the general distribution of the upstream migrants shown in the table.

Depth interval	South	Mid-channel	North
I	148	23	96
II	141	57	120
III	111	111	172

Utilization of slack water areas behind training walls

The results indicate that the majority of adult salmon ascending the lower Fraser during the study period (non-freshet conditions) did not move shoreward of structures as they migrated through reaches of the river influenced by existing training walls. All radio-tagged sockeye and chum salmon that were tracked successfully on a continuous basis as they moved up the river through the trained reach remained in the main channel (Figs. 2-4). None of the fish moved laterally into calmer water behind training walls.

However, it was apparent from hydroacoustic monitoring that a small proportion of migrants do move shoreward of training structures (i.e. behind the walls). At transecting Station 2 (Fig. 1), surveys were conducted across the river to include the slack water shoreward of the downstream end of the rock wall structure at the Fraser Surrey Container Dock. During transects completed 21 September to 1 October sockeye size targets were identified on the shoreward side of the structure. The numbers of targets detected in the main channel and in the slack water behind the training walls at Station 2 are shown in Table 5. For both ebb and flood tide, the majority (79.2%) of targets were on the main channel side of the structure and only 20.8% were detected shoreward of the structure. When tidal influence is considered, however, the mean number of fish found shoreward of the structure was marginally ($p < 0.07$) greater during flood tide.

Behaviour of fish in slack water areas shoreward of training structures

To determine whether salmon utilize 'fishways' incorporated into the upstream ends of training walls, hydroacoustic data were collected with a stationary, down-looking transducer floated in the upstream opening of the training structure at the Fraser Surrey Container Dock (Fig. 1). Continual acoustical monitoring of targets passing through the opening was undertaken from 2000 hours on 20 September through 1400 hours on 22 September 1978. Target detection per hour in the fishway is shown in Fig. 5. The average detection rate of 4.3 targets per hour indicates that migrant salmon continually use the fishways incorporated into this training wall.

An increase in the number of targets passing under the transducer was noted during ebb tide when downstream river velocities are higher. In contrast, during flood when downstream velocities are slower, target detection in the fishway tended to be less frequent. Adult salmon that move out of the river mainstem into the slack water area shoreward of training walls, therefore, appear to be capable of negotiating the main channel through fishways and probably do so by orienting to downstream flow through these openings.

Exit of radio-tagged fish from behind training walls

In order to evaluate if migrants can become disoriented behind training walls or are induced to delay for long periods, radio-tagged chum and sockeye purposely were released shoreward of two training structures: the Annacis piling wall on the north side of the river and the rock wall on the opposite bank. Return of the tagged fish to the main channel was recorded by mobile tracking vessel or, alternatively, by the stationary receiver on the bridge at New Westminster.

All fish released behind the structures returned to the main channel. Exit times for the tagged fish are shown in Table 6. The average exit time was approximately 5 hours following release. Four of the six fish for which a continuous track was confirmed entered the main river channel via the downstream end of the training structures. The tracks for three of these fish (No. 1, 2 and 8) are shown in Fig. 4. For two chum (Track nos. 9, 14; Table 6) moving downstream behind the Annacis Island training wall when radio contact was lost, exit times of about 10 hours were estimated from the ground speed made by other radio-tagged chum salmon and the difference in time from last radio contact with these two fish and their arrival at the bridge receiver. Thus, following re-orientation to main channel flows, all subjects moved up the main channel.

If adult salmon purposely move into slack water behind the training structures to rest and hold, or if they "wander" behind the structures, they appear capable of re-entering the main channel in two ways. Either they utilize fishways incorporated into training walls or drop downstream and re-orient to the main channel flow.

DISCUSSION

The migration rates of chum, sockeye and pink salmon in the lower Fraser determined in the past have been based on information derived from the commerical fishery and mark-recapture experiments. These earlier results provide a base for comparison with the rates of movement exhibited by the radio-tagged fish.

Ward (1959) described the character of the Fraser River pink salmon migration during 1957. Based on commerical fishery interception of migrants, pinks in marine waters moved from the San Juan Islands to Point Roberts at a rate of 99.8 km/day (1.15 m/sec). Following river entry, the population then progressed from Sandheads to the Glen Valley area downstream of Mission at a rate of 37 km/day (0.43 m/sec). Upstream of this point the pinks slowed to 19.3 - 19.7 km/day (0.20 - 0.22 m/sec). Ward (1959) concluded that pink salmon did not delay following entry into the lower river but, rather, they moved rapidly and quickly upstream. In comparison to pink salmon, chum salmon moved upriver at a slower rate. This species, on average, negotiates the river from its mouth upstream to Mission at a rate of 20.9 km/day (0.24 m/sec). However, there appear to be substantial yearly variations. In 1964 the rate was 32.2 km/day (0.37 m/sec), whereas in 1965 the chum migration speeds were lower at 16.1 km/day (0.19 m/sec); upstream of Mission to spawning grounds the chum migration rate decreased to 3.2 - 8.0 km/day (0.04 - 0.09 m/sec) (Palmer, 1972).

Sockeye salmon show variation in migration speeds between distinctrive races. Generally, early races move through the river faster than late races. Killick (1955) identified three types of sockeye behaviour by studying the consistency of chronological order during migrations. The first type is exhibited by the June and July runs of early Stuart, Bowron and Horsefly races which move upstream at a rate of 48.3 km/day (0.56 m/sec). The Chilko and Stellako races enter the river in early August and migrate at a slower rate of 33.8 - 35.4 km/day (0.39 - 0.41 m/sec). The Adams run enters the river later (mid-September) and migrates even slower at 27.4 km/day (0.32 m/sec). In other river systems speeds appear similar; for example, Becker (1962) found sockeye in the Kvichak River in Alaska migrating upstream at a rate of 0.46 m/sec.

The mean speeds of migration exhibited by the radio-tagged chum and Adams sockeye released during the present study appear considerably faster than those reported earlier. The chum salmon moved through the river at a rate of 0.46 m/sec (Table 1), twice the previous reported average rate of 0.24 m/sec. Similarly, the sockeye moved approximately twice as fast (0.55 m/sec) as the previously reported rate of 0.32 m/sec for the Adams race of this species. It is not known whether the faster speeds exhibited by the radio-tagged fish can be

attributed to a more precise monitoring technique, the small sample size used, or to some combination of other factors. For example, subject fish were tracked only in the lower reaches of the river while earlier studies estimated the speeds over longer sections from the river mouth at Sandheads to Mission and, furthermore, indicated that migratory progress decreases in upriver areas. Secondly, only those radio-tagged fish that moved consistently upstream were included in the calculation of migration rates and this behaviour pattern may not be typical of the total population. The present findings do, however, quantify migration rates attainable by individual fish that are actively and consistently moving upstream.

Weaver (1963) demonstrated that adult chinook, coho and steelhead usually showed preference for and will select channels with higher water velocities, indicating that adult salmonids use flow as a migration cue. In addition, it has been shown that adult salmonids negotiating fishways delay entrance if flow is not maintained or if they are presented with a number of conflicting flow cues (Environment Canada, 1974). With flood tide and the effective damping of channel velocities within tidal reaches of the river, fish would not have the higher downstream flow to act as a cue promoting orientation and movement in an upstream direction. Thus, the higher velocity in trained sections, possibly coupled with more uniform flows, may have stimulated the faster swimming speeds observed (Table 3).

The migration strategy of adult salmon ideally could be seen as one of optimally balancing swimming speed, energy conservation, and transit time against arrival at the spawning ground when nearing completion of sexual maturation. It would seem advantageous also that a migration strategy be dynamic and capable of responding to a number of factors such as river velocities, tidal influence, salt wedge penetration, and specific timing of river entry by individual species and races. The migration speeds and behaviour reported in the present study, similar findings by others related to variable swimming speeds over longer sections of the river (Killick 1955; Palmer 1972; Ward 1954), and preference by several species of adult salmon for higher river velocities (Weaver 1963) would be at odds with the notion of a fixed migration strategy. When the fish are in the lower tidal reaches of the river and in contact with saline water, they may still be in a kind of staging mode and not "committed" to upstream migration. This is indicated in the present study where distribution and relative abundance did not show effects of tide (i.e. river velocity), vertical or horizontal stratification, nor interaction of these stratification factors with tide (Table 4, Stn. 4). In the trained section of the river the response of both sockeye and chum to the higher velocities with higher swimming speeds (Table 3) may be related to the preference shown by other salmon species for higher water velocities (Weaver 1963). If an unknown length of high velocity river section is encountered, such as a trained section, the strategy of increased swimming speed would be preferred since the cost of energy reserves ultimately could be greater if a more moderate, energy-conserving swimming speed incurred a longer transit time to the spawning ground. The slower swimming speeds in upriver sections (Palmer 1972) and a favoured distribution to the slower flowing bottom and side channels as indicated in the Mission hydroacoustic data (text Table, p. 5), would be consistent with a strategy achieving relatively faster, or at least equivalent, transit time while conserving energy reserves.

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Table 1. Speeds of upstream migration exhibited by radio tagged sockeye and chum salmon released in the lower Fraser mainstem. The plotted path (Track Nos.) for some of the tagged fish are shown in Figs. 2-4.

Track No.	Species	Total Distance Travelled upstream (m)	Transit time (sec)	Ground speed (m/sec)	(L/sec)[1]
2	sockeye	6,845	14,100	0.48	0.81
3	sockeye	19,200	36,000	0.53	1.13
8	sockeye	3,225	8,400	0.38	0.63
10	sockeye	8,720	10,000	0.81	1.35
			Mean:	0.55	0.98*
			± SD:	±0.18	±0.32
6	chum	4,755	10,500	0.45	0.61
9	chum	3,475	18,900	0.18	0.22
11	chum	7,825	14,400	0.54	0.71
12	chum	11,965	19,800	0.60	0.76
15	chum	10,235	15,900	0.64	0.75
16	chum	13,125	57,300	0.23	0.31
17	chum	9,315	16,500	0.56	0.70
			Mean:	0.46	0.58
			± SD:	±0.18	±0.22

[1] L = body lengths.

* sockeye mean L/sec significantly greater than chum ($p < 0.05$); t-test, pooled S^2

Table 2. Comparison of the speeds of upstream migration over flood and ebb stages of the tidal cycle for individual radio tagged sockeye and chum salmon released in the lower Fraser mainstem. The plotted paths (Track Nos.) for some of the tagged fish are shown in Figs. 2-4).

Track	Species		Ground Speed			
			Flood tide		Ebb tide	
			(m/sec)	(L/sec)[1]	(m/sec)	(L/sec)
2	sockeye		0.40	0.67	0.57	0.95
3	sockeye		0.54	0.90	0.49	0.82
10	sockeye		0.65	1.08	1.11	1.85
		Mean:	0.53	0.88	0.72	1.21
		± SD:	±0.12	±0.21	±0.34	±0.56
12	chum		0.59	0.75	0.65	0.82
15	chum		0.64	0.75	0.63	0.74
16	chum		0.24	0.32	0.10	0.14
		Mean:	0.49	0.61	0.46	0.57
		± SD:	±0.22	±0.25	±0.31	±0.37

[1] L = body lengths

Table 3. Comparison of the speeds of upstream migration through trained and untrained sections of the lower Fraser River for individual radio-tagged sockeye and chum salmon released in the lower Fraser mainstem. The plotted paths (Track Nos.) for some of the tagged fish are shown in Figs. 2-4.

Track	Species		Ground Speed			
			Trained section (m/sec)	Trained section (L/sec)[1]	Untrained section (m/sec)	Untrained section (L/sec)
3	sockeye		0.94	1.56	0.54	0.90
10	sockeye		1.11	1.85	0.71	1.18
		Mean:	1.03**	1.71**	0.62	1.04
		± SD:	±0.12	±0.21	±0.12	±0.20
12	chum		0.65	0.82	0.51	0.64
15	chum		0.75	0.88	0.49	0.58
17	chum		0.66	0.82	0.47	0.58
		Mean:	0.69*	0.84**	0.49	0.60
		± SD:	±0.06	±0.03	±0.02	±0.03

[1] L = body lengths

* $p < 0.05$, ** $p < 0.025$: for each species, mean speed greater in trained section; paired t-test.

Table 4. Probability values for analysis of variance of Fraser River hydroacoustic transecting data. Transecting stations are shown in Fig. 1.

Factor	Transecting station		
	upstream		downstream
	1	3	4
Tide	$p < 0.05$	$p < 0.10$	n.s.*
Horizontal distribution	n.s.	$p < 0.05$	n.s.
Vertical distribution	$p < 0.10$	n.s.	n.s.
Interaction: horizontal distribution vs tide	n.s	$p < 0.05$	n.s.
Interaction: vertical distribution vs tide	n.s.	n.s.	n.s.

* n.s. - not significant

Table 5. Comparison of the numbers of salmon-sized targets detected shoreward of the training wall and in the mainstem at hydroacoustic station 2. The number of targets behind the training wall was marginally greater ($p < 0.07$) on flood tides (t-test, pooled S^2).

Date	Tide stage	Number of targets	
		Main channel	Behind structure
21/09/78	ebb	25	2
22/09/78	ebb	7	1
23/09/78	ebb	16	3
30/09/78	ebb	1	1
30/09/83	ebb	3	0
01/10/78	ebb	3	2
22/09/78	flood	9	5
23/09/78	flood	11	3
24/09/78	flood	2	3
24/09/78	flood	7	2
	Total:	84	22
	% of total targets detected:	79.2	20.8

Table 6. Exit times for radio-tagged salmon released behind training structures. The plotted paths for Track nos. 1, 2, and 8 are shown in Fig. 4

Track no.	Species	Exit Time (hrs)
1	sockeye	1.5
2	sockeye	Immediate
6	chum	2.0
8	sockeye	3.5
9	chum	10.5
14	chum	10.0

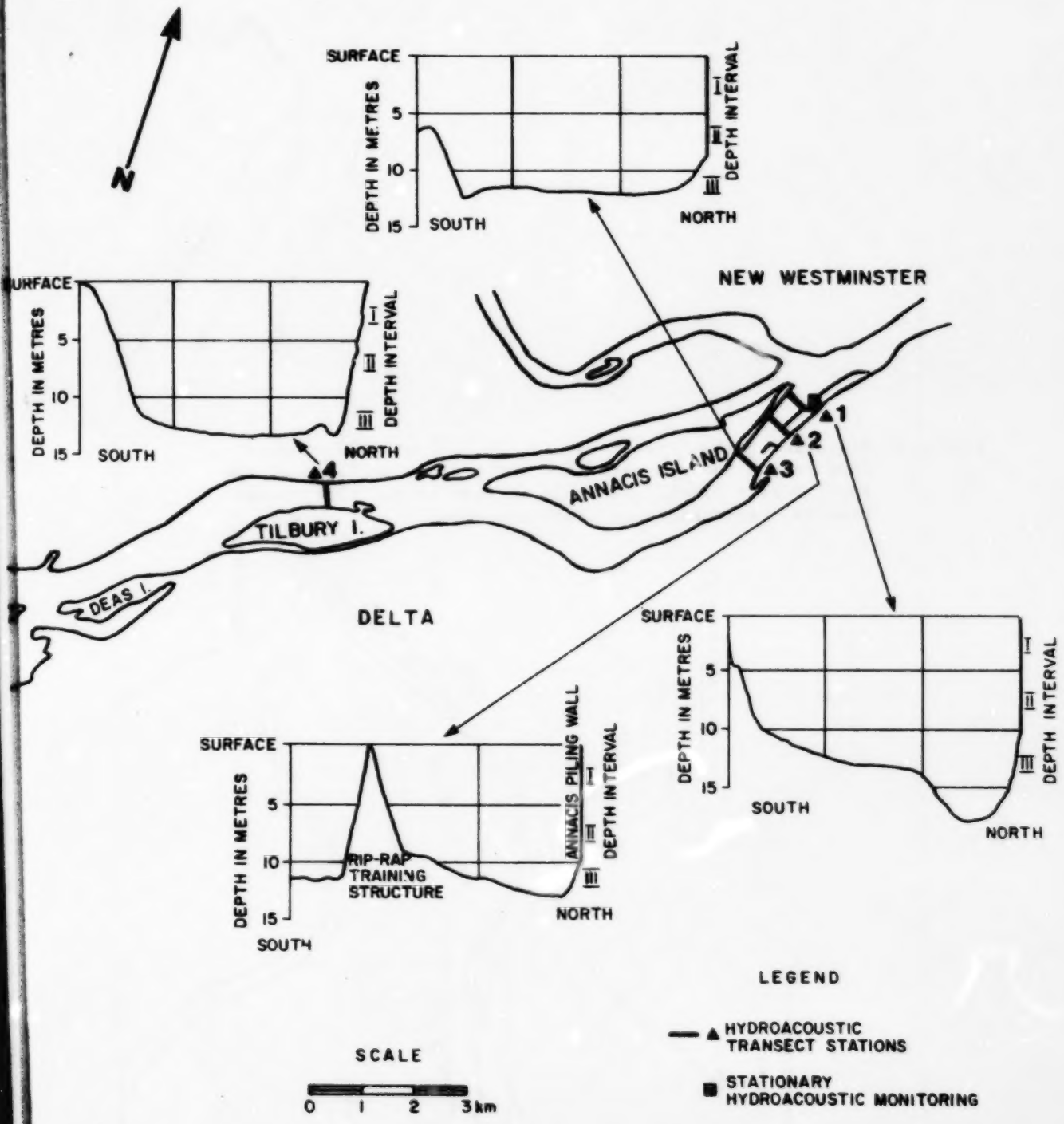


Figure 1. Hydroacoustic transect and stationary monitoring locations in trained and untrained sections of the lower Fraser River.

Figure 2. Migration paths (track nos. 15, 16, 17) of radio-tagged chum salmon through untrained and trained sections of the lower Fraser River. The bold portion on the tide curves (insets) represents the tracking period.

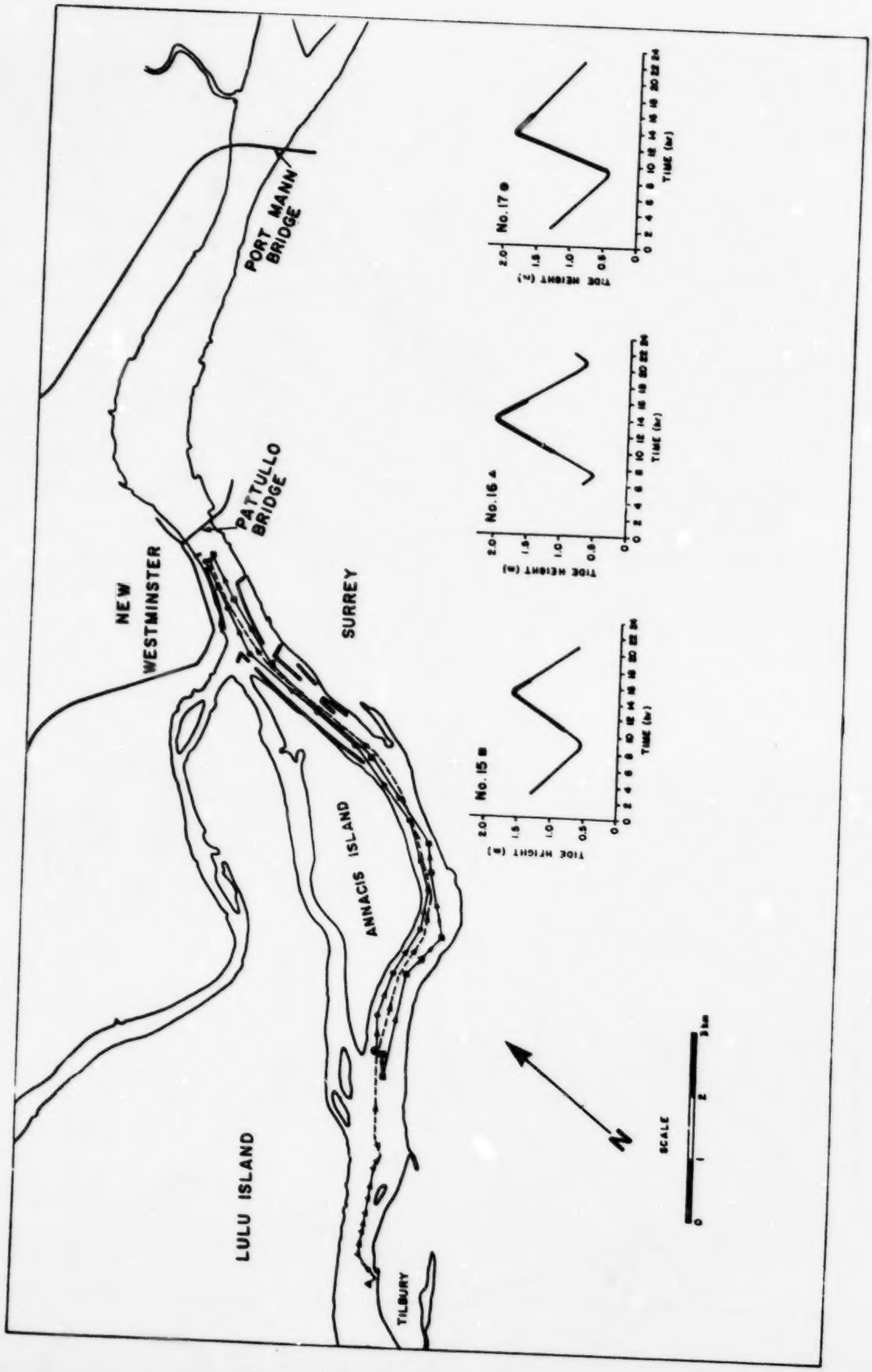

PORT MANN BRIDGE
PATTULLO BRIDGE
NEW WESTMINSTER
SURREY
ANNACIS ISLAND
LULU ISLAND
TILBURY
No. 15
No. 16
No. 17
TIME (hr)
SCALE
N

Figure 3. Migration paths (track nos. 11, 12, 13) of radio-tagged chum salmon through untrained and trained sections of the lower Fraser River. The bold portion on the tide curves (insets) represents the tracking period.

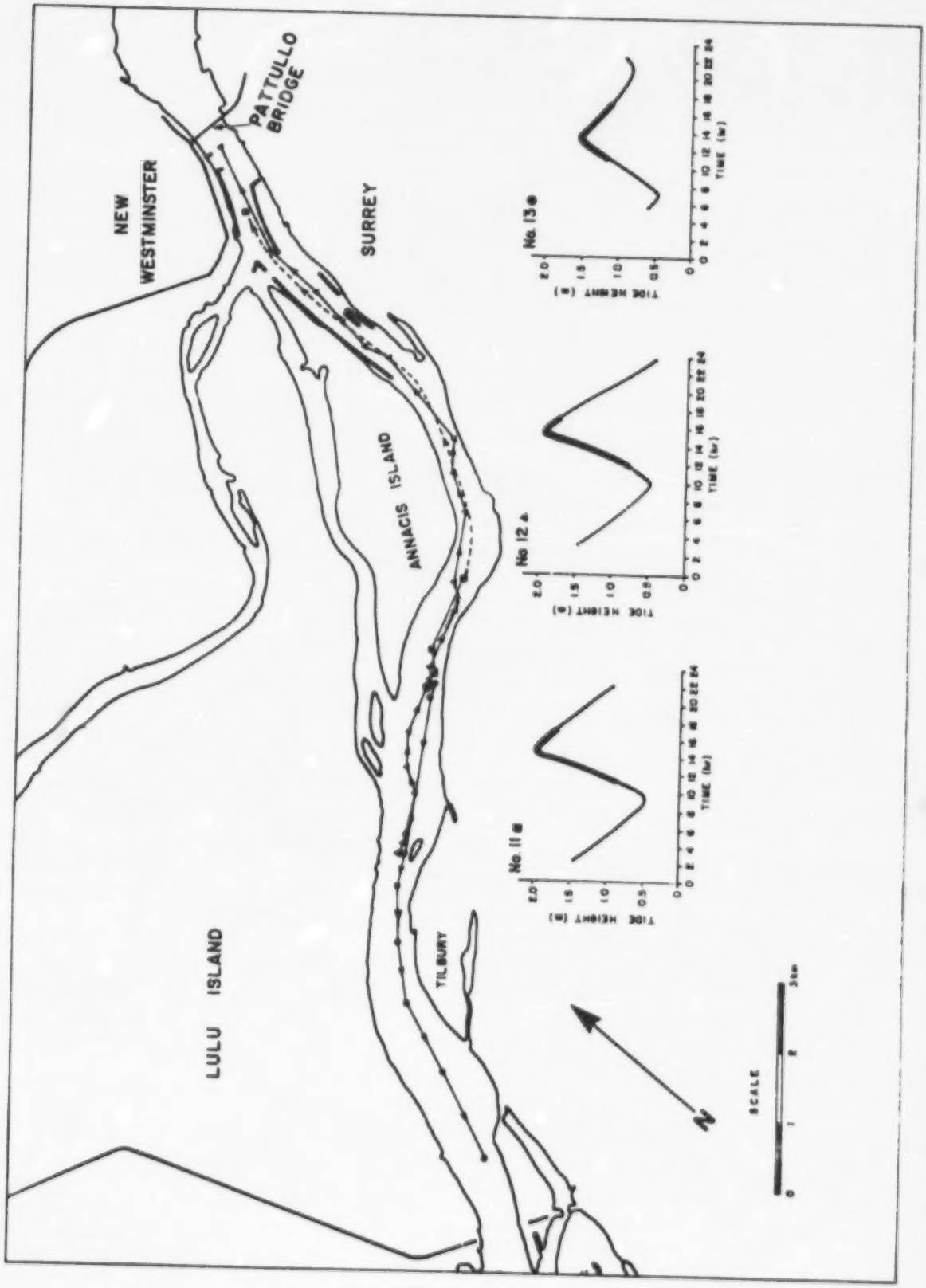

NEW WESTMINSTER
PATTULLO BRIDGE
SURREY
ANNACIS ISLAND
LULU ISLAND
TILBURY
No. 11
No. 12
No. 13
TIME HEIGHT (m)
TIME (hr)
SCALE
N

Figure 4. Migration paths (track nos. 1, 7, 8) of radio-tagged sockeye salmon released in slack water behind training structures in the lower Fraser River. The bold portion on the tide curves (insets) represents the tracking period.

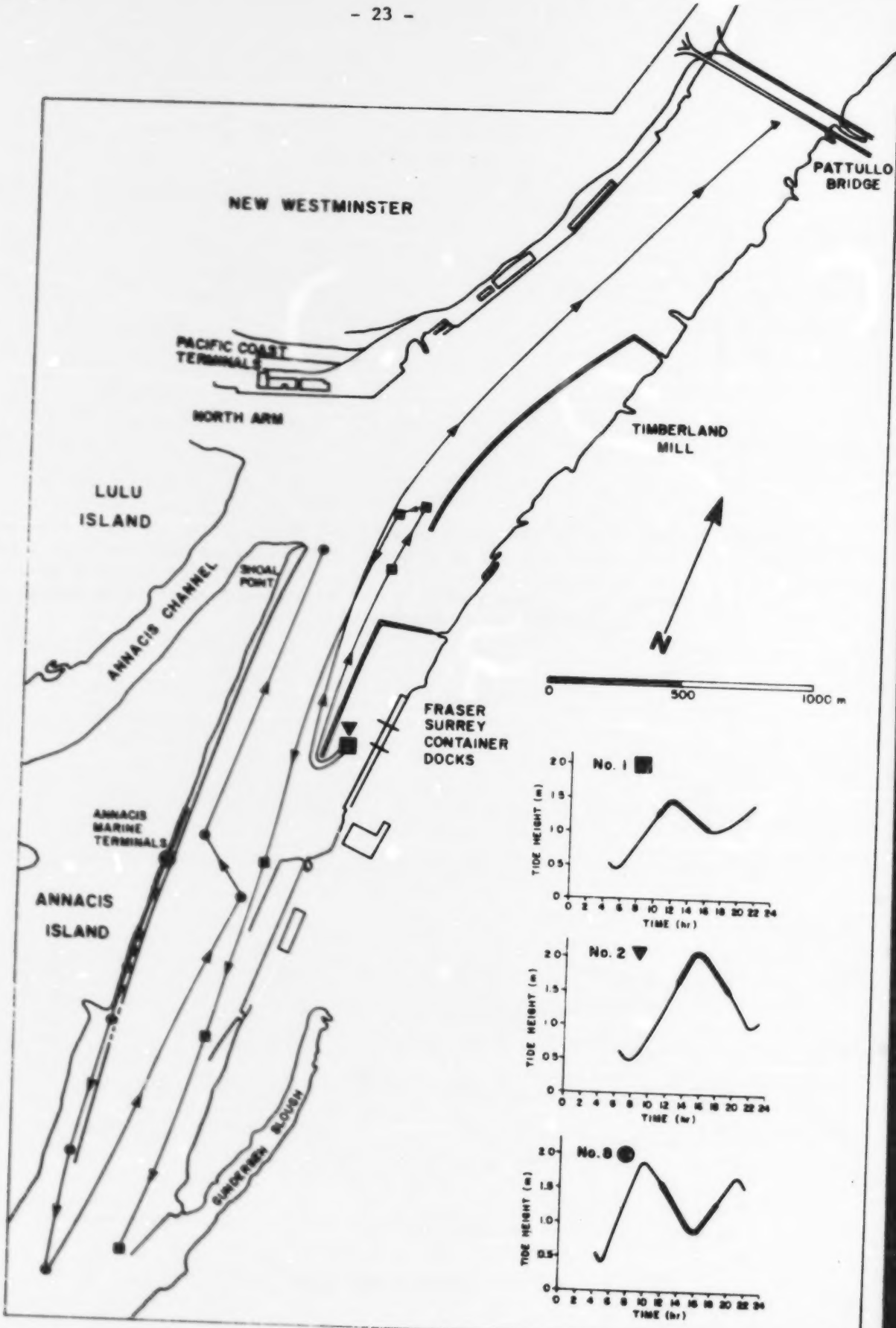
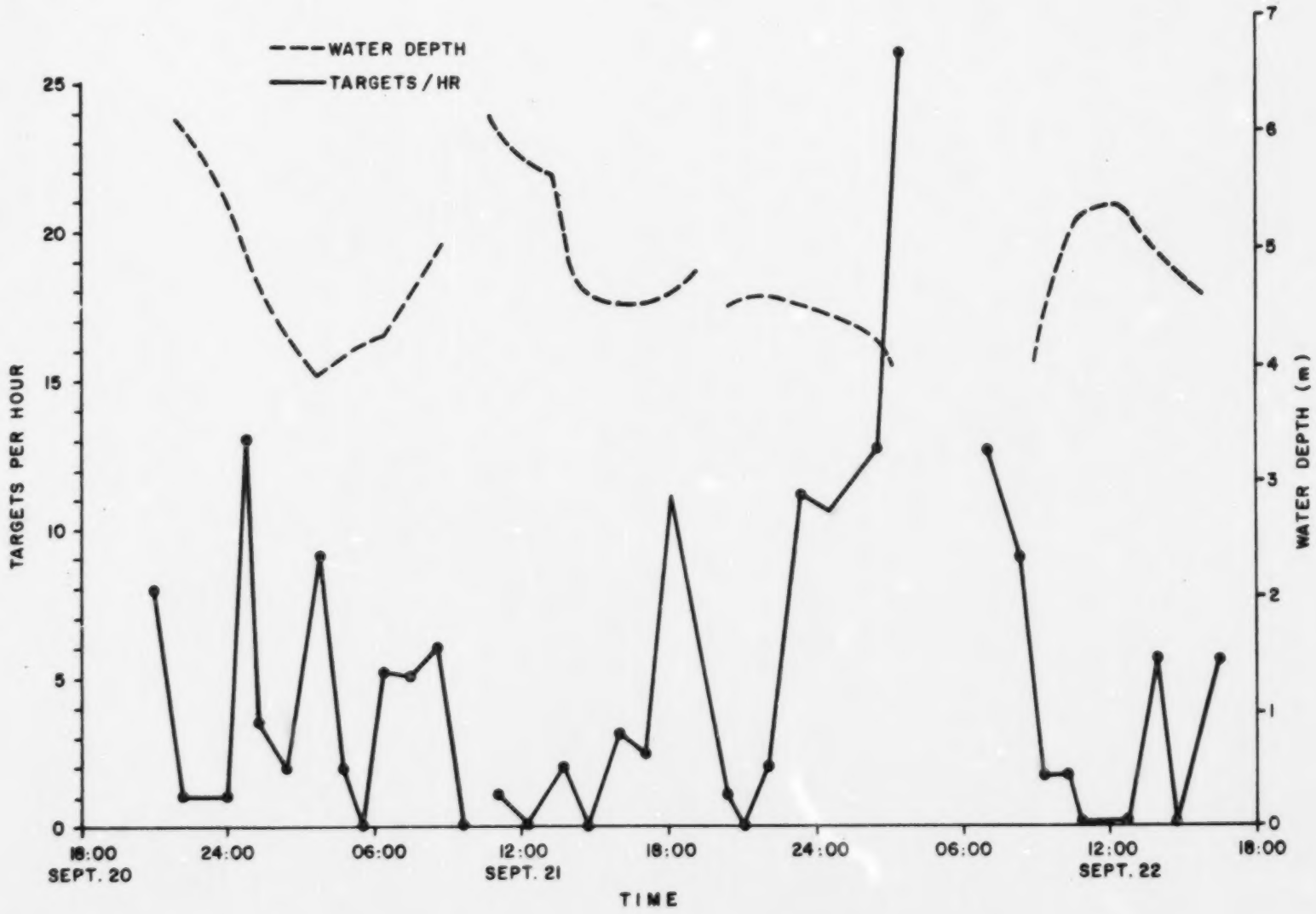

NEW WESTMINSTER
PATTULLO BRIDGE
PACIFIC COAST TERMINALS
NORTH ARM
TIMBERLAND MILL
LULU ISLAND
ANNACIS CHANNEL
SHOAL POINT
FRASER SURREY CONTAINER DOCKS
ANNACIS MARINE TERMINALS
ANNACIS ISLAND
GUNDERSEN SLOUGH
N
0
500
1000 m
No. 1
No. 2
No. 3
TIDE HEIGHT (m)
TIME (hr)

Figure 5. Number of salmon sized targets per hour exiting the fish passage in the upstream end of Fraser Surry Container Dock training structure. The water depth curves indicate tidal effects at the fish passage location. Discontinuity in the targets and water depth curves are due to discontinuous observations.


WATER DEPTH
TARGETS / HR
TARGETS PER HOUR
WATER DEPTH (m)
25
20
15
10
5
0
7
6
5
4
3
2
1
0
18:00
SEPT. 20
24:00
06:00
12:00
SEPT. 21
18:00
24:00
06:00
12:00
SEPT. 22
18:00
TIME